

#### (iv) Fuses

Commercial A-M receivers rarely incorporate a fuse owing to the difficulties involved in providing a satisfactory one. The peak current in the primary of the power transformer when a receiver is switched on may be twenty times the average current for a time not exceeding 0.01 sec. This occurs during normal operation, but on the other hand a fault resulting in twice the normal primary current over a period of time may lead to transformer breakdown.

Since a normal cartridge fuse will blow within 0.01 sec. with five to ten times its rated current applied, a fuse of four times the rated current of a receiver would be the smallest value which could be used. Such a fuse would probably not fail immediately, even with a complete short circuit on the whole high tension winding of a receiver, and would be almost useless.

Two types of fuse which can be used satisfactorily under such conditions have been described (Ref. 30). The first consists of the normal glass cartridge and ends, containing in series a small spring soldered under tension to a fine manganin resistance wire by means of a blob of low temperature solder (e.g. Wood's metal). A prolonged overload produces enough heat in the resistance wire to melt the solder and allow the fuse to clear, but the thermal inertia of the mass of solder protects the fuse against short duration surges. With a severe overload the resistance wire clears almost instantaneously. An advantage of this type of fuse is the low temperature required for operation—of the order of 100°C compared with perhaps 900°C for a normal type of fuse.

Another fuse has been made consisting of a high melting point nickel wire with blobs of magnesium powder in a binding varnish supported on it. Once again the thermal inertia of the blob allows short duration surges to occur without damage, but a prolonged overload raises the magnesium powder to ignition point (about 500°C) and the fuse clears.

A different type of protection has been used in other types of receivers. This consists of an insulated strip of metal with high heat conductivity which is included in the power transformer during winding. One end of the strip projects outside the winding and to this a small stirrup is soldered with very low melting point solder. A spring engages in the stirrup under tension and the primary current to the whole receiver passes through the assembly. Any overheating of the power transformer melts the solder and the spring disconnects one side of the mains from the receiver. Such a device might not protect a low impedance rectifier from damage if the input condenser were to break down, but it could save the power transformer and would certainly prevent a fire.

(30) Strafford, F. R. W. "Mains transformer protection" *W.W.* 53.2 (Feb. 1947) 51; correction 53.3 (Mar. 1947) 94.

# MAINS TRANSFORMER PROTECTION

## Fuses Designed to Withstand Initial Switching Surges

IT is a significant fact that the great majority of radio sets and electronic instruments embodying a mains transformer do not include fuse protection in series with the primary winding. The socket connection to the mains is generally backed by a fuse in the electric wiring of the building, but these fuses are invariably of 5 amp. or 15 amp. rating, and any defect in the apparatus giving rise to abnormal loads on the transformer would burn out the transformer long before the 5- or 15-amp. fuse cleared.

Since the cost of a small cartridge fuse and its holder is quite small compared with the cost of a mains transformer there do not appear to be economic grounds for its omission, particularly in high-grade laboratory equipment.

The reason for its omission is not difficult to establish. The simple type of cartridge fuse (Fig. 1 (a)) consisting of a filament of wire enclosed in a glass tube is not capable of withstanding the switching surge if its rating is equal, or near to, the rated current consumption of the equipment. This leads to the inclusion of a fuse of higher rating which will not clear on the switching surge. Unfortunately, the rating now becomes so high that the fuse will sustain overloads capable of burning out the mains transformer before the fuse clears.

At this stage it will be of interest to discuss the mechanism by which these switching surges are produced. An investigation was undertaken in which a number of pieces of laboratory apparatus were individually connected to the mains via a suitable recording device, to trace the amplitude and waveform of the primary current from the moment of

switching on. It was observed that quite a large number of switchings could be made in which no surge occurred. This indicated that the moment of switching relative to the cycle of the applied E.M.F. is important.

The exact moment of switching, to provide the desired test surge is in the neighbourhood of that part of the applied E.M.F. wave

where it is falling through zero amplitude and is also partly dependent upon the effective R/L ratio of the transformer referred to the primary circuit. The phenomenon has been analysed for an air cored inductance, and it is found that if an inductance of low R/L ratio (high Q) is connected to a source of alternating E.M.F. at the instant it rises through zero amplitude, the current which flows will rise to exactly twice the steady-state peak amplitude

rise to an even higher value, and it is easy to visualise that this will tend to give a cumulative effect which comes into equilibrium by somewhat complicated energy transfer processes. For the types of transformers we are discussing, the surge can attain amplitudes some twenty times greater than the steady-state peak values of input current.

In examining the results of the tests carried out on a number of representative transformers two important characteristics were noticed. First, the duration of the surge never exceeded one half-period of the frequency of the applied E.M.F. The experiments were conducted using the 240-V, 50-c/s mains supply so that the surge never lasted longer than 0.01 sec. Secondly, the amplitude of the surge was not materially changed by "hot" or "cold" switching; i.e., whether the switching operation took place when the apparatus had been previously operated or not.

At this stage we will neglect the question of these surges and consider whether the simple type of fuse, as previously described, is likely to protect the average mains transformer of the type we

have in mind, when faults arise causing excessive secondary loads.

Now, in accordance with British Standard Specification 646, a "B" category fuse (60 mA to 5 A) shall rupture within 1 minute where the current is 1.75 times the rated current. Starting on this basis transformers were first loaded on their secondaries

until their design rating was attained, and a fuse of appropriate rating was included in series with the mains supply. The transformer was allowed to run for at least one hour under these conditions to attain temperature equilibrium. Inciden-

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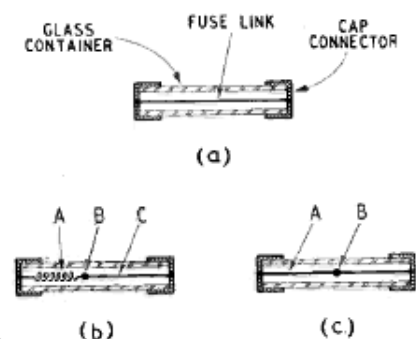
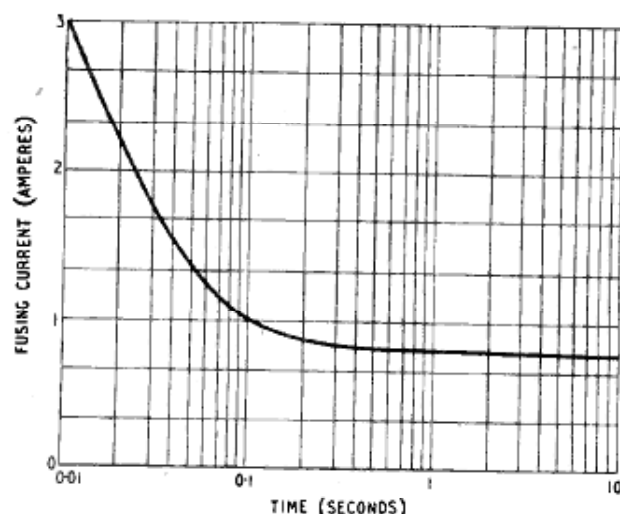


Fig. 1. (a) Simple cartridge fuse. (b) Spring-loaded fuse with low melting-point connection. (c) Magnesium-loaded nickel fuse.

For reasons of economy, it is usual to select a cross-section of iron that gives this condition, so that any current over and above the rated current for the transformer will reduce the inductance. But this reduction in inductance will tend to cause the current to

### Mains Transformer Protection—

tally, the transformers tested were of the conventional type employing two valve heater secondaries and a 350-0-350-V H.T. secondary.



fuses and maintain the 75 per cent overload for exactly 1 min, which is the top limit of the specification. Under these conditions the average temperature of the windings did not rise by more than 10° C. By holding the overload for 3 mins the temperature rose by 20° C.

It is clear that these temperature rises are not dangerous for a well-designed transformer, so that

Fig. 2. Time taken to blow fuse at various currents for a 0.5 amp fuse to specification B.S.646.

By short-circuiting any one of these three windings the fuse cleared instantly. It was noted, by separate measurement without a fuse in circuit, that short-circuiting a 4-volt winding caused the primary current to rise by 140 per cent. Short-circuiting the 6.3 volt winding caused a 300 per cent increase, and short circuiting the 350-0-350-V winding a 700 per cent rise. Fuses designed to B.S. 646 (category "B") will clear instantly on 100 per cent or greater overloads, a result verified by the foregoing short-circuit tests.

Reverting to the previous set-up (where the transformer was correctly loaded) each secondary winding was individually loaded until the primary current was 1.75 times the rated current. As would be expected the fuses cleared within 1 minute in each test. During the period prior to fuse clearance the average temperature of the windings was checked by noting the rise in winding resistance and employing the formula  $R_T = R_0 [1 + \alpha T]$ , from which one obtains  $T = \frac{R_T - R_0}{\alpha}$ , where

$R_0$  is the resistance at 0° C, and  $\alpha$  is the temperature coefficient of resistance. Most of the fuses cleared within 15 secs. and it was difficult to determine the temperature rise because of the lack of time to make observations. It was decided, therefore, to remove the

in the event of a fault causing the primary current to rise by a factor of 75 per cent or greater, a simple cartridge fuse designed in accordance with B.S.646 (category "B") would undoubtedly protect the mains transformer from breakdown.

Thus the only deterrent to the wider use of B.S. 646 cartridge fuses for the class of application

transformer with which the radio and electronic industry are concerned) appear to reach, in the worst cases, some twenty times the normal rated peak current.

The simple type of cartridge fuse, covering ratings from 100 mA to 3 A, appears to possess a surge factor from 5 to 10 times the peak rated current. In a large majority of cases, therefore, such fuses will be blown by switching surges if their current rating is matched to the transformer rating.

The problem of protecting a transformer is thus one of designing a fuse which will meet the B.S. 646 specification in regard to the 1 min. overload test, but which will carry at least thirty times its rated current for a period of 0.1 sec.

In Germany a popular method of meeting this surge-resisting requirement is obtained in the manner indicated in Fig. 1(b). A coil of springy wire, A, is soldered by means of a blob, B, of low-temperature solder (e.g. Woods' Metal) to a fine manganin resistance wire C. The assembly is mounted under the spring tension in a glass tube and capped as in the familiar fuse construction. Under a prolonged overload of, say, two minutes, sufficient heat is

generated by the resistance wire to melt the solder blob and the spring thus snatches the junction of A and C apart and clears the fuse. The temperature rise to cause disruption need only be of the order of 100° C, whereas

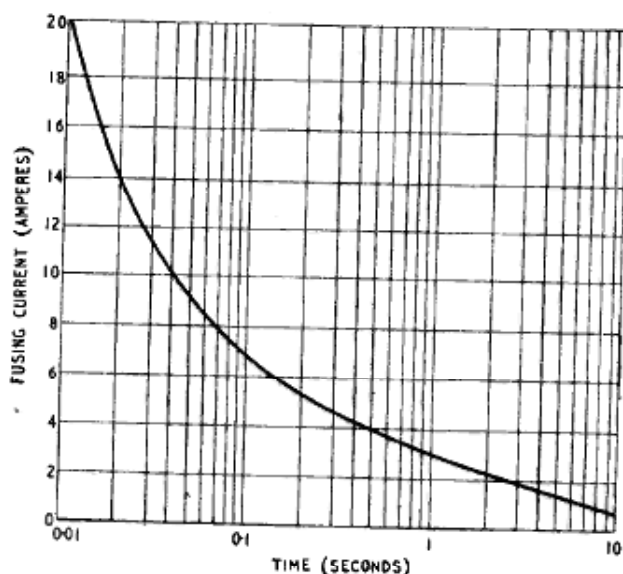


Fig. 3. Fusing current/time curve for magnesium-nickel fuse rated at 0.5 amp.

we have been discussing is their inability to withstand large current surges for a period of up to about 0.01 sec.

It was previously pointed out that these surges (for the type of

for the filament type fuse this may be 900° C or more according to the metal or alloy employed. Very sudden surges of large amplitude will not generate sufficient heat in the blob to cause it

to melt, due, of course, to its large diameter relative to that of the wire, and its consequent high thermal inertia. The limit to the surge-handling capacity is set where the heat produced by the current is sufficient to raise the fine manganin wire to its melting point.

Naturally the greater skill and time taken to manufacture this type of fuse is reflected in its greater cost of production as compared with the single-filament conventional fuse. Fuses constructed in this manner will, however, protect transformers, and themselves, by virtue of their complete ability to withstand switching surges.

Another method\* has been developed which permits of a construction whose difficulty lies about midway between the German fuse and the conventional type. The physics of its operation is quite different, however, and is as follows. A high melting point nickel wire A in Fig. 1(c) is made up into a conventional type fuse with the exception that it carries a small blob B of magnesium powder held together by a suitable binding varnish.

Now magnesium has a very great affinity for oxygen when its temperature is elevated, and at about 500° C it burns spontaneously, generating an intense heat. By careful manufacturing control of the diameter of the magnesium blob it is possible to manufacture fuses which will satisfy B.S. 646 long-time blowing requirements, but which will possess, in addition, a surge factor of approximately 40 times the rated current, thereby removing completely the disadvantage of the simple fuse.

Fig. 2 depicts the relationship between the fusing current and time for a 0.5 amp. rating fuse of the conventional type. This should be compared with Fig. 3 which represents the short time performance of a delay fuse embodying the magnesium nickel principle and designed also for 0.5 amp. rating.

While both fuses clear in about 10 seconds at 0.875 amps. (75 per cent overload) the delay fuse requires 20.0 amps. to clear it

in 0.01 secs. as compared with 3.0 amps. for the simple fuse.

In practice it is usual to employ two blobs of magnesium per fuse, and these are respectively at about  $\frac{1}{3}$  and  $\frac{2}{3}$  of the length of the nickel element. The reason for this is to provide insurance

in the event of one blob failing. The reason blobs are not placed in the centre is because, where the wire heats and expands, this region is obviously the more liable to touch the glass walls of the fuse container and inhibit blowing.

\* Patent No. 473,335.